The Miniaturized Autonomous Moored Profiler (Mini AMP)

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LONG-TERM GOALS

High resolution, 4-D environmental characterizations of the physical and bio-optical structure of the near shore and coastal oceans are needed in order significantly improve our understanding of the complex biogeochemical processes acting these regions. Accurate assessments of the vertical structure of the physical, optical, and biogeochemical properties in the coastal environment are also vital to many naval operations (i.e. MCM, ASW). Furthermore, the development of a national backbone of observing systems envisioned for the US coastal regions requires reliable, affordable, autonomous monitoring stations to provide early warning indicators of events and trends. As such, there is a definite need for the development of intelligent, reliable, high resolution, moored profiling systems. The long-term goal of this project is to develop a compact, low power, autonomous, scalable, bottom-up profiling system, termed the **Mini**aturized **A**utonomous **M**oored **P**rofiler (**Mini AMP**), to support a variety of long-term coastal applications, where real-time, high vertical resolution physical and bio-optical data are required. The focus of this development effort is to provide a system that offers the user a high level of flexibility in sensing parameters, data telemetry and data control, while maintaining a high level of performance, reliability, accuracy, and ease of use.

OBJECTIVES

In review of the specifications and design analysis completed in Phase I, we determined a set of tasks that provide a logical path for proceeding with the Mini AMP Phase II development efforts. The primary goal of these tasks is to implement and validate two profilers. The primary embodiment of the Mini AMP profiler includes an onboard winch system, a data acquisition/package controller, a suite of sensing systems (CTD, radiometer, and optical sensors), a power system (power management and battery pack), and a telemetry system. These units will see extensive field use by scientists within the community on an iterative basis allowing for a phased testing and development of the Mini AMP system. This evaluation must satisfy peer-review, a key requirement in demonstrating to the research community that the platform is operational and to ensure the viability of the end product. This testing will be coordinated with ongoing naval efforts and other science research community activities. This process of testing and refinement is an ongoing effort, with the primary objective to produce two field tested and validated Mini AMP profilers which will be used as the working prototypes for transitioning the systems to a commercial product.

APPROACH

The approach taken in the development of the Mini AMP system is:

1. *Construction of an alpha Mini AMP prototype.* Construction of the alpha level Mini AMP prototype will be accomplished using a phase iterative approach. Initial work will focus on development and testing of the Mini AMP structural body, shell and buoyancy modules. Development of the winch system, package and winch controllers, the bio-optical sensing system, and power module will be conducted concurrently, with each subcomponent subsequently integrated and tested with the Mini AMP platform.

2. *Alpha Mini AMP prototype implementation development and testing*. Upon completion of the alpha Mini AMP prototype, we will begin a series of implementation testing to develop and evaluate operational performance. In each case we will define specific benchmarks to define levels of system operation. With regard to this our first goal will be to develop operational capabilities for inner coastal waters (to 30 meters). Tests will focus on all aspects of deployment including deployment, cycling and retrieval.

3. *Conduct design review of alpha Mini AMP.* We will conduct a design review to determine what design modifications are required prior to and concurrent with fabrication of the next Mini AMP platform. The results of the design review will provide a pathway for developing the Mini AMP to a beta prototype level.

4. *Construct and implement beta Mini AMP prototypes*. We will undertake the development of the beta Mini AMP systems in a similar style to the initial alpha Mini AMP, through a series of iterative modification, implementation and testing cycles. The existing alpha Mini AMP will first undergo this developmental cycling to upgrade the system to a beta level prototype. An additional beta Mini AMP prototype will be constructed at this stage after modifications based on the design review have been completed.

5. *Remote host interface software development*. The objective of this phase of development will focus on providing an intuitive GUI-based host package for the Mini AMP to control and configure instrumentation, power management, profiling operations, remote telemetry, data compression and storage, post-processing and data display. Several iterations of the software development will be necessary, including primary package controller firmware development, to enable all desired features.

6. *Beta Mini AMP prototype operational testing.* The developmental cycle will cumulate in a series of operational deployments of the two beta Mini AMP prototypes in a variety of environmental settings. The primary objective of this phase will be to demonstrate the operational performance of the Mini AMP system over a range of near shore and ocean conditions, and to evaluate the utility and easy of use of the system. The approach taken in this phase will be to partner with various research groups around the country to implement the Mini AMP in coordination with their individual research projects.

7. *Produce and submit Phase II final report*. The deliverables for the Phase-II contract will be 1) two fully functional beta-level Mini AMP prototypes and 2) the Final Report detailing our accomplishments, testing results, and platform performance.

A team of engineers at WET Labs has been dedicated to the development of the Mini AMP profilers, and has been working on producing the alpha level prototype over the nine months. Currently, 6 engineers have been involved in the development, with each being tasked with the design of specific components. An undergraduate student (Margaret Plank) from Colorado State University spent the summer working closely with the Mini AMP engineering team through an internship. She played a key role in the design and construction of the level wind assembly to be used with the alpha Mini AMP prototype.

Dr. Percy Donaghay and Dr. James Sullivan of the University of Rhode Island are serving as consultants on this project. Dr. Donaghay and WET Labs have extensively collaborated with each other for the past 8 years in development of several generations of high-resolution vertical profilers called the ORCAS profilers. Dr. Sullivan as part of his post doctoral research with Dr. Donaghay worked extensively on development of the winch to be adapted for this project. He has also heavily collaborated with WET Labs engineers in developing operational capabilities with the present generation of moored profilers co-developed with the company. Both Drs. Donaghay and Sullivan are playing key roles in the initial implementation testing of the alpha Mini AMP prototypes and are leveraging their existing efforts utilizing the ORCAS profilers in the ONR LOCO project in the development of the Mini AMP.

WORK COMPLETED

Over the past 9 months, we have completed various design and testing phases of the Mini AMP system. These include:

1. *Testing and verification of profiler tether material*: We have extensively evaluated Plasma® rope for use with the Mini AMP system. Tests conducted include creep/elongation susceptibility, abrasion wear, snap strength, and level wind performance. For the given specifications of the Mini AMP (profiling speed, length, duration), the Plasma® rope was shown to exceed these specifications with the exception of its abrasion properties. The abrasion of the rope was found to be effectively minimized by using low friction components (ceramic eyelets) on the level wind and fairlead.

2. *New winch motor and controller design and construction*: We evaluated several different servomotors to use with the Mini AMP winch assembly in terms of power consumption, torque limits, gearing, rotational rate and precision. A QuickSilver Controls, Inc. motor was selected based on the Mini AMP specifications and their motor controller functionality. We also have an extensive knowledge base in working with the manufacturer from our previous ORCAS development activities.

3. *New winch system designed and constructed*: A right angle worm gear design for the winch motor was developed primarily based on the Mini AMP desired form factor and reduce axial loading on the winch shaft assembly. A further advantage of this design is that the winch drum and level wind assemblies are more modular, and thus are easier to service without having to compromise the entire winch motor assembly. It also makes the system scalable, in that various winch drum sizes and level winding speeds can be accommodated without having to adjust the motor assembly. This new winch system is shown in figure 1 and consists of a winch motor assembly (motor, gear, shaft, seals, housing), a worm gear drive, a winch drum assembly, and a level wind assembly. The separate winch drum and level wind assembly is scalable such that the user can easily modify the winch drum size (to accommodate different deployment depths) and the level wind speed. The alpha level winch system prototype has been constructed and is currently undergoing performance testing. This system will be incorporated with the alpha level Mini AMP body prototype and will subsequently be deployed in Newport Bay, OR.

4. *New level wind assembly designed and constructed*: A level wind assembly has been design and constructed based on a screw drive mechanism (see figure 1). A ceramic eyelet has been built into the level wind assembly to reduce abrasion of the Plasma® rope. A scalable gear box has also been designed to accommodate a broad range of profiling speeds. These gears can easily be accessed and configured by the user to tune the level wind traveling speed to insure and even and consistent layering of the rope on the drum. A fairlead assembly that is connected to and extends below the winch drum assembly (not shown in figure 1) has been constructed.

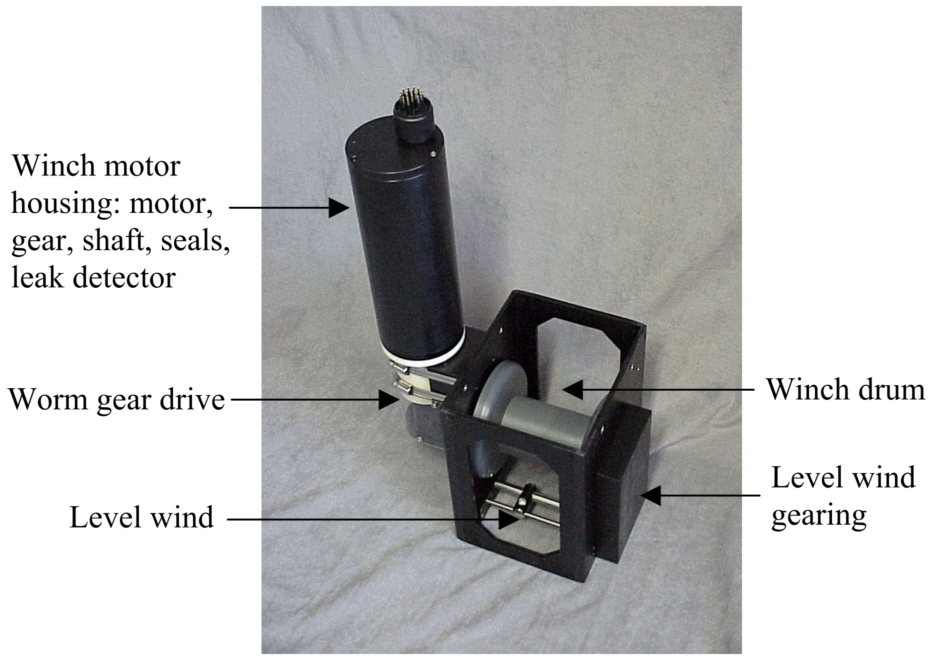

Figure 1. Picture of the alpha level winch system and level wind prototype to be used on the Mini AMP system. Note that this new design incorporates a right angle worm gear drive such that the winch motor can be oriented parallel to the main framing structure of the Mini AMP, while maintaining the drum alignment at the base of the center of gravity on the profiler.

5. *Alpha prototype body assembly designed and being constructed*: The alpha level Mini AMP body, framing and support structure is currently being constructed to accommodate the winch assembly. The primary purpose of constructing this alpha level support structure is to provide a mechanism to obtain data on the hydrodynamic stability of the tear drop shape envisioned for the Mini AMP system. Shown in figure 2 is a drawing of this alpha level design. The primary purpose is to obtain data on how the form factor and weight distribution envisioned for the Mini AMP affects the overall stability and profiling performance of the system. The final body and framing structure design we expect will be modified significantly as we obtain results from various deployments.

6. *Winch and package controller development*: The approach taken in developing the controls of the Mini AMP is to combine a series of modular control systems, with each system having supervisory roles. The winch package controller primary function is to initialize and control the winch motor, to

monitor the status of the motor, to control the direction and rate of the motor, and to monitor the attitude of the package during the profiling sequence. The function of the package controller is to control the power to the various subsystems, to initialize and control the instrument suite, to control data acquisition and telemetry, and to act as the primary profiler system status supervisory agent. Both board stacks are using similar microcontrollers (Persistor Inc CF2) which will reside in a single housing within the Mini AMP. Currently, the winch controller has been developed and constructed. The package controller electronics and firmware are currently being designed.

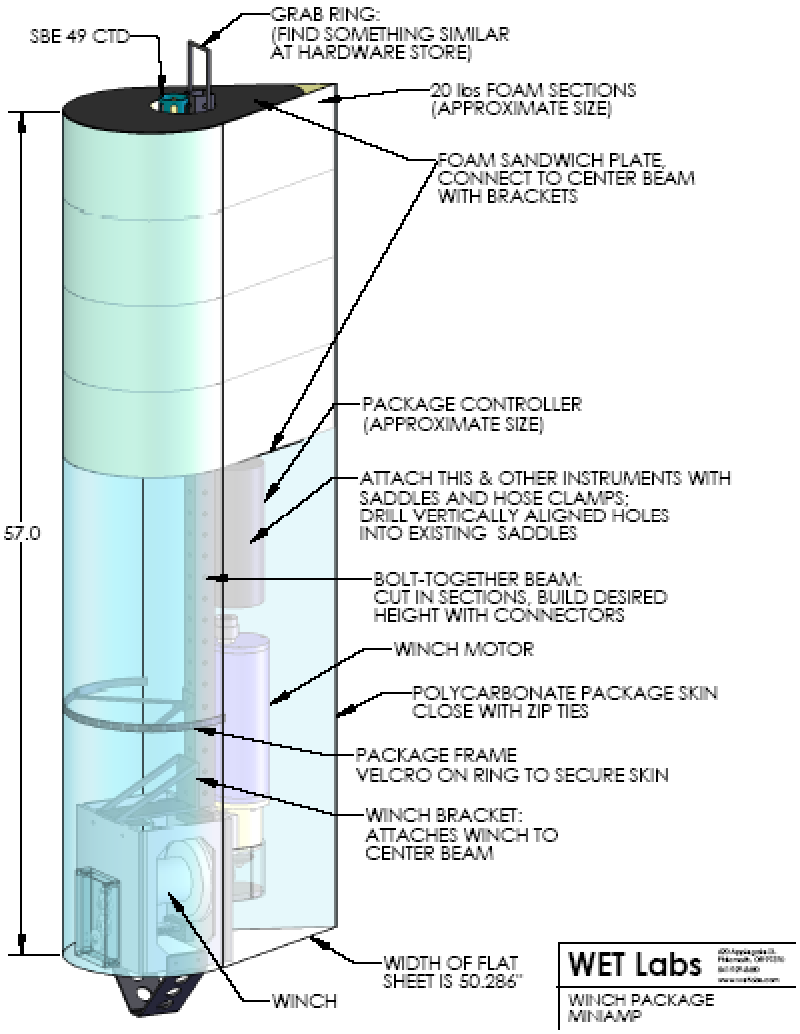

Figure 2. Drawing of the alpha level Mini AMP prototype. This system is currently being constructed and will be deployed in Newport Bay, OR in the fall of 2005 to collect data on the performance of the winch system and the hydrodynamic aspects of the body design.

RESULTS

Significant testing was done to evaluate using Plasma® 12 strand rope as the tether material for the winch system. Testing was done to simulate wear induced on the rope induced by the level wind and winch drum assemblies. Long term testing (100 km traversed) revealed than the Plasma® material was susceptible to friction abrasion from the fairlead assembly. A ceramic eyelet was incorporated into the fairlead design, which dramatically decreased the abrasion of the rope over the same test procedures. In fact, over 100 km traversed, the rope saw minimal degradation due to abrasion or elongation (less than 10%). Plasma® rope was also incorporated into an existing moored profiler system (the ORCAS profilers) for the ONR LOCO experiment in August/September of 2005. These systems previously used stainless steel wire braid as the tether material, and were highly susceptible to bail jumping and birds nesting which would cause the profiler to cease operation. During the 5 week deployment period of the ORCAS profilers during the LOCO experiment, no problems related to the Plasma® rope were encountered, and the wear on the rope was minimal. Thus, we have concluded through testing and field evaluations that the Plasma® rope is the material of choice for the Mini AMP system.

We have also been conducting extensive testing on the seal design for the winch motor system. The key to an effective, low maintenance, reliable winch system is dependent on an effective seal system to prevent leakage of water along the motor shaft into the motor housing. Various lip seals (similar to the ones used on the ORCAS winches) were evaluated, and were found to be insufficient over long-term testing cycles. These seals wear at a rate that does not meet the Mini AMP specifications (over periods of weeks as opposed to months). Thus, various other seals have been considered and are currently being evaluated. A ceramic face seal, similar to ones used in the well water pump industry, has been incorporated into the Mini AMP winch system design and is currently undergoing extensive performance testing. Preliminary results from these tests indicate that these seals wear at a much slower rate than the lip seals, and are also less susceptible to uneven wear induced by slight shaft misalignment.

As noted in the Work Completed section, we are currently in the process of completing the construction of the alpha level Mini AMP prototype. Over the next few months, we have several deployments of this prototype scheduled, primarily in Newport Bay, OR. We are also planning on scheduling week long testing periods where the profiler will be deployed in a variety of dynamics environments. The focus of these deployments is to obtain data on the winch system performance, the profiler control functionality, and the hydrodynamic stability of the Mini AMP design. The approach taken is an iterative one, where extensive testing is followed by further modification and enhancement. Thus we anticipate that the next few months will provide valuable results on the functionality and performance of the Mini AMP prototype design.

IMPACT/APPLICATIONS

The Mini AMP system will have immediate applicability for military operations requiring 4-D (space and time) knowledge of optical and physical properties within the battle space environment. These include optics-based mine and submarine countermeasures involving models of diver visibility, diver vulnerability, and radiative transfer, and lidar-based detection systems. Optical properties are also widely used by the non-military research community to determine a variety of water biogeochemical properties, including particle concentration, composition, and turbidity. The Mini AMP is designed to meet the needs of applications demanding autonomous, long-term high vertical resolution profiles of physical and optical parameters from a platform that is small, robust, low maintenance, and hydrodynamic. Many compact, cost-effective observation platforms are being sought after by the Navy and the ocean research and observing communities such as the NSF ORION and IOOS activities. Since there is currently no platform commercially available that fulfills all of these needs, there is a market vacuum for such a system. We believe that the innovations of the Mini AMP system will fill a unique niche in ocean research that will service a broad spectrum of coastal oceanographic research and military needs.

TRANSITIONS

There is a great demand for autonomous, moored profiling capabilities not only within the naval realm, but also in the science research, ocean observing and resource management communities. This has become clearly evident since initiation of our development activities of the Mini AMP, as we have received numerous inquiries as to the status and potential availability of the Mini AMP system. As one of the key goals of the project is to provide a profiling system that not only meets naval needs, but also to provide a turnkey solution to future and existing ocean observing and monitoring installations, we feel the involvement of these groups are crucial to insuring that the Mini AMP system will meet a broad spectrum of user's needs.

Recently, the NOAA Chesapeake Bay Office (NCBO) released a solicitation for the procurement of a continuous, real-time, shallow water, tethered profiling water quality and bio-optical property measurement system. This was a result of many conversations with Doug Wilson of the NBCO who became aware of our Mini AMP development project through our web site. He expressed an interest in working with us to support the profiler development to meet the ecosystem resource management observing needs of the NCBO. As a result, we responded to the NOAA solicitation and were awarded the procurement to deliver a Mini AMP prototype to the NCBO by the fall of 2006. We feel that this partnership with the NOAA NCBO will insure an effective transition of the Mini AMP technology into the resource management and ocean observing arenas.

RELATED PROJECTS

We have been working closely with Drs. Donaghay and Sullivan (University of Rhode Island) on the development of the Mini AMP and to support their profiling systems (ORCAS) in the ONR LOCO project. This support has occurred hand in hand with the Mini AMP development in order to take advantage of the past combined experience of both groups. In August and September of 2005, WET Labs engineers provided substantial support to Drs. Donaghay and Sullivan deployment and operation of the ORCAS systems during the LOCO field experiment in Monterrey Bay, CA.

In February of 2005, Drs. Jack Barth and Murray Levine of Oregon State University (OSU) was awarded an NSF grant through the Oceanographic Technology and Interdisciplinary Coordination program to develop in partnership with WET Labs a coastal autonomous profiling and boundary layer observing system. WET Labs role in this project (through a subcontract to OSU) was to develop a 250 m depth deployable autonomous moored profiler for the coastal environment, termed the X10 profiler, as well as an underwater docking and recharging system for the X10. This development is substantially different from the ONR supported Mini AMP project. First the X10 profiler will have and extended depth range (250 m) and deployment range (6 months) than the Mini AMP profiler (100 m, 3-6 months). Second, the instrumentation suite included in the X10 will accommodate a factor of 2 more sensors than the Mini AMP. Third, the X10 power system will be recharged underwater when docked in a bottom anchor/monitoring platform (the Mini AMP power system is completely self contained). Lastly, the mode of telemetry between the two systems is substantially different. A more detailed description of this project is given in *McLean and Barnard, 2005*. While there are substantial differences between the X10 and Mini AMP, the core technology of a winch on board design is consistent between the two, and thus we have been leveraging much of the winch development.

PUBLICATIONS

McLean, S. and A. Barnard. 2005. Next generation ocean observing systems – Enabling new science. *Ocean News and Technology* 11(2): 46-49.